

Dec. 31, 1957

M. F. GOERTZ ET AL
STRESSED FERRITE CORES

2,818,514

Filed Oct. 2, 1952

2 Sheets-Sheet 1

FIG. 1

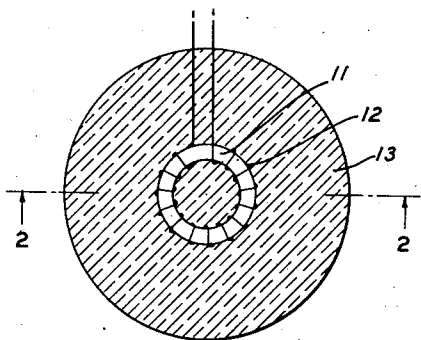


FIG. 2



FIG. 3

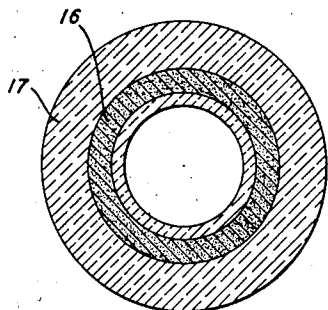


FIG. 4

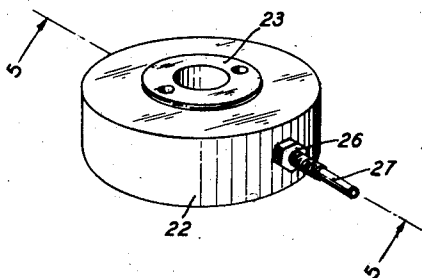


FIG. 5

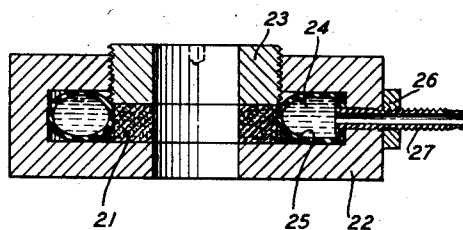
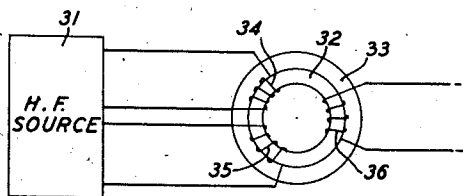


FIG. 6



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FIG. 7

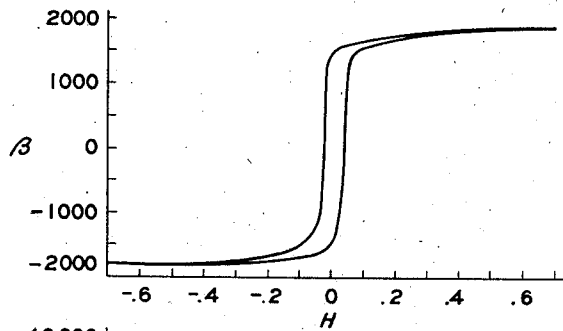


FIG. 8

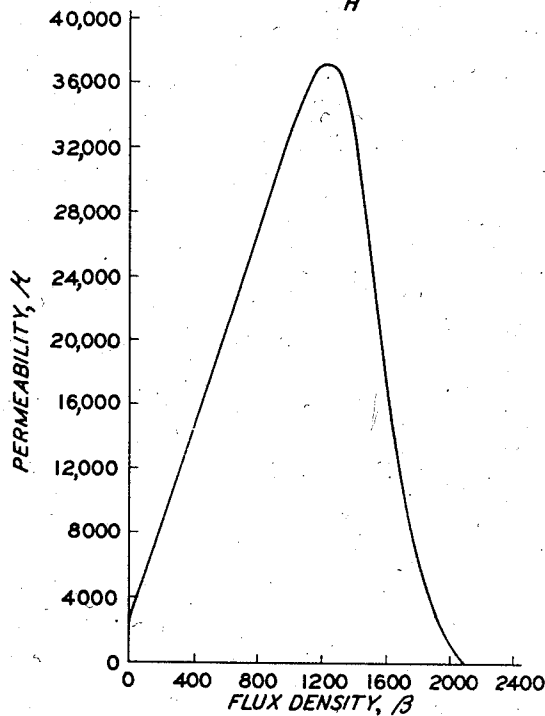
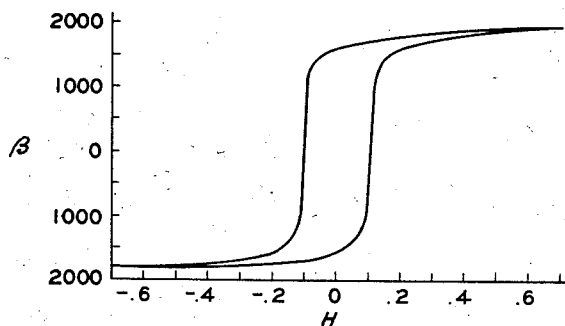


FIG. 9



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STRESSED FERRITE CORES

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Application October 2, 1952, Serial No. 312,746

16 Claims. (Cl. 310-26)

This invention relates to high frequency magnetic cores made of ferrite.

It has previously been proposed to use ferrites as magnetic cores, with considerable emphasis being directed toward the improvement of their magnetic qualities through the elimination of all stresses including magnetostrictive stresses. Substantial effort has gone into the development of particular polycrystalline ferrites having substantially zero magnetostrictive qualities.

We have found, however, that the high frequency magnetic properties, and more especially the maximum permeability and the remanence of cores composed of magnetostrictive ferrites can be greatly improved by maintaining them under proper stress.

Accordingly, one object of the invention is to improve the magnetic characteristics of high frequency ferrite cores.

A further object is to actively stress an annular magnetic core parallel to the closed magnetic circuit simply, inexpensively, and without increasing the high frequency electrical losses.

In one embodiment, an annular ferritic core having a chemical composition of $\text{Ni}_{0.3}\text{Zn}_{0.7}\text{Fe}_2\text{O}_4$ is embedded in a plastic of a kind which shrinks as it solidifies, so that uniform radial compressive stress is maintained of a value such that the maximum permeability and remanence are increased three and fourfold, respectively, and the hysteresis loop tends to become more nearly rectangular.

Other objects and advantages of the present invention will be apparent from the detailed description of certain specific devices illustrating the principles of the invention, which are shown in the drawings.

In the drawings:

Fig. 1 illustrates a ferrite core embedded in a constrictive type plastic;

Fig. 2 is a cross-sectional view of the device illustrated in Fig. 1 taken in a plane through 2-2 of that figure;

Fig. 3 shows an alternative stressed core structure using a constrictive plastic matrix;

Fig. 4 represents a structure in which a ferrite core is stressed by hydraulic pressure;

Fig. 5 is a view showing a cross-section of Fig. 4;

Fig. 6 is a schematic circuit diagram illustrating the use of stressed ferrite cores; and

Figs. 7, 8 and 9 are plots of the magnetic properties of materials under stress.

Before commencing a detailed description of the drawings, the development of ferrite cores will be reviewed briefly to aid in the understanding of the present invention.

Although the ancients recognized the magnetic properties of magnetite, or magnetic iron ore Fe_3O_4 , it was not until comparatively recently that the increased interest in high frequency circuits for many communications purposes led to a dissatisfaction with the high frequency losses of conventional metallic cores, and to a renewed interest in the non-metallic magnetic ferrites. At the beginning of this period of renewed interest, the values

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of initial permeability obtainable from the known ferrites were as follows:

Ferrite	Initial permeability
FeFe_2O_4 (normal)	Approximately 10.
FeFe_2O_4 (stress-free)	Approximately 70.
CuFe_2O_4 (quenched)	Do.
MgFe_2O_4	Maximum approximately 10.
NiFe_2O_4	Do.
CoFe_2O_4	Scarcely 1.
MnFe_2O_4	Maximum approximately 250 (but inconsistent).

as set forth on page 356 of an article by J. L. Snoek, entitled "Non-metallic Magnetic Material for High Frequencies," Philips Technical Review, volume 8, No. 12, pages 353-384, December 1946. By using polycrystalline specimens, however, of a formula such as $(\text{XY})\text{Fe}_2\text{O}_4$, where (XY) represents one molecular weight of two divalent metals, it was found that improvements in the foregoing values were possible. In addition, at the time when this investigation into the properties of magnetic oxides was begun, the theories of Kussman, Becker, and Kersten had indicated that the "absence of stress was an essential condition for high initial permeability and low hysteresis loss" (quoted from the above-noted article by J. L. Snoek, one of the pioneers in this field). As the study of polycrystalline ferrites continued, it was found that by combining proper proportions of ferrites having positive and negative magnetostrictive properties, that is, which respectively expand or contract in the principal direction of magnetization, the magnetostriction of the polycrystalline constructure can be reduced to almost zero, and the resultant core is substantially stress-free.

The foregoing mode of attack, including the elimination of magnetostrictive stresses, has, indeed, resulted in ferrite cores having sufficiently improved magnetic qualities that they are now extensively used for many high frequency applications. In accordance with the present invention, however, it has been determined that by choosing a polycrystalline ferrite having a suitable magnetostrictive characteristic (other than zero) and subjecting it to stress, the magnetic properties of the ferrite will be greatly improved and made superior to those of ferrites made in the usual manner. Thus, although certain isolated instances of the recognition that stresses caused slight changes in the magnetic properties of metallic ferromagnetic materials may be found in the prior art, it is considered that this step, as applied to the present type of non-metallic ferrite cores, was entirely contrary to the line of development which had been pursued by those skilled in this field. Furthermore, the preferred embodiment of the invention, which is an annular ring of a particular polycrystalline ferrite embedded in a non-conducting constrictive plastic, is an exceedingly simple and inexpensive stressed core, having excellent magnetic properties, and little or no eddy current losses at high frequencies.

Referring more particularly to the drawings, Fig. 1 illustrates a stressed ferrite core assembly in which the annular ferrite core 11 has one or more copper windings 12 inductively linked therewith, and the core and windings are embedded in an insulating constrictive plastic body 13. In accordance with one example of the invention, the core may be made from a negative magnetostrictive nickel-zinc ferrite, the windings from insulated fine copper wire, and the plastic of a material known commercially as Selectron 5003, which is a rigid styrene-polyester casting resin which shrinks approximately nine percent during curing. While the foregoing materials have proved satisfactory, other suitable negative magnetostrictive ferrites and constrictive insulating materials

may also be employed. In particular, other shrinking insulating materials which have shrinkage factors of the same order of magnitude as the nine percent mentioned above could be used advantageously. From one or two percent shrinkage factor, which would be required to set up a useful stress in the core, up to about twenty percent, at which point the internal stresses make the body of the plastic break open as it cures, would be included in this range. The approximate dimensions of the stressed core assembly shown in Fig. 1 are $2\frac{1}{4}$ inches diameter by $\frac{3}{16}$ inch thickness, with the ferrite core having a diameter of approximately $\frac{3}{4}$ inch and a cross-section approximately $\frac{1}{8}$ inch square. In addition, the coil or coils are normally of a relatively few number of turns or are moderately loosely wound in order to minimize interference with the constrictive effect of the plastic.

Fig. 2 is a cross-sectional view of Fig. 1 which shows the relative thinness of the core assembly, and the substantial radial and small axial extent of the enclosing plastic matrix. The purpose of this dimensioning is to insure the application of sufficient radial stress on the ferrite core, and to prevent axial shrinkage from interfering with this radial stress. The uniform inward force on the annular core creates a strong internal compression of the core along its circular extent, coincident with its closed magnetic circuit. This compression establishes a direction of easy magnetization parallel thereto, and the annular core tends to assume the magnetic characteristics of a single crystal, having one axis of easy magnetization.

In the fabrication of the core assembly illustrated in Figs. 1 and 2, a suitable polymerizing catalyst is added to the casting resin. The ferrite core is then submerged in the liquid as by pouring the liquid over the core, and it is subjected to moderately increased temperature for several hours to accelerate the curing process. In one instance, using the Selectron 5003 mentioned above, a peroxide polymerizing catalyst and a cobalt promoter, the assembly was held at 45° C. for fifteen hours, at 80° C. for eighteen hours and at 120° C. for one hour, in successive stages. The foregoing times are merely illustrative of the length of time required for curing and shrinkage of the particular casting resin, and are by no means critical. When the promoter is not used, somewhat higher temperatures and longer times are required. In addition, the coils on the magnetostrictive core may be electrically energized in the proper direction to reduce the diameter of the core as the plastic cures, and thus add to the deformation and stressing of the core. The electrical current would be maintained until the plastic solidified, and, upon its release, the relaxation of the magnetostrictive deformation would tend to place the core under stress even without shrinkage of the plastic.

The core assembly of Fig. 3 includes the ferrite core 16 embedded in constrictive plastic matrix 17 with the core and plastic body being of approximately the thicknesses shown for the comparable elements of Fig. 2. This type of core is suitable for magnetic coupling to one or more straight conductors or a single-turn coils such as may be used in static storage arrays for digital computers and the like.

Figs. 4 and 5 illustrate an alternative arrangement for compressing the core which was used in testing a number of annular core specimens. In the operation of this device, a ferrite core specimen 21 is first inserted into the recessed annular brass casing 22, and the threaded brass retaining plug 23 is screwed into place. Hydraulic pressure is then applied to the oil 24 within the rubber tube 25 which encircles the core 21. The nut 26 holds the oil inlet copper tube 27 securely in place. In operation, various pressures may be applied to the ferrite core through a suitable gauged hydraulic pressure system, and the magnetic properties of the ferrite core tested by means of a coil threaded through the open center of the unit.

Fig. 6 illustrates a schematic circuit diagram including a high frequency source 31, a stressed ferrite core 32

embedded in a lossless insulating matrix 33, and several coils 34, 35 and 36 linking the core with the high frequency source and other electrical apparatus (not shown). When used in magnetic memory devices or in storage arrays the low loss non-conducting ferrite core assemblies may be used at much higher pulse repetition rates than the metallic ferro-magnetic storage elements which have been widely used heretofore. Similarly, the upper frequency limit of other devices such as magnetic amplifiers may be extended by the use of these stressed ferrite cores.

The remarkable properties of stressed ferrite core assemblies in accordance with the invention may be better appreciated by reference to the plots of Figs. 7 to 9 and the following table:

Specimen No.	Atomic percent using 100% metal base	Comp.	B _r , Gauss	B _m , Gauss	B _r /B _m	H _c , Oers.	H _m , Oers.
1	66.67 Fe—10.0 Ni—23.33 Zn	(o) W/C	320 1,460	1,720 1,870	0.18 0.78	0.7 0.7	0.02 0.03
2	67.54 Fe—9.69 Ni—22.77 Zn	(o) W/C	900 1,630	1,640 1,930	0.55 0.84	0.7 0.7	0.07 0.10
3	67.09 Fe—9.82 Ni—23.09 Zn	(o) W/C	730 1,250	1,700 1,780	0.43 0.70	0.7 0.7	0.02 0.04
4	66.27 Fe—10.07 Ni—23.66 Zn	(o) W/C	470 1,260	1,700 1,850	0.28 0.68	0.7 0.7	0.03 0.07
5	65.95 Fe—10.17 Ni—23.88 Zn	(o) W/C	460 1,370	1,350 1,880	0.34 0.73	0.7 0.7	0.13 0.11
6	67.11 Fe—32.89 Ni—9 Zn	(o) W/C	820 1,730	1,400 1,980	0.59 0.87	17.5 17.5	9.5 12.5
7	Mn—Zn—Ferrite	(o) W/C	750 550	2,190 1,330	0.34 0.41	0.7 0.7	0.3 0.10

In the foregoing table, the column headed "Comp." indicates whether the measurements are in the unstressed state (o), or with compression (W/C). B_m stands for maximum flux density at the peak applied magnetic field, B_r is the remanence or residual flux density, H_c is the coercivity, and H_m stands for the peak magnetic field applied to the specimen.

In the interpretation of these figures and the table of data, it may be noted that an improvement in the rectangularity of the hysteresis loop, as indicated by the remanence (B_r) may be noted in almost every instance where the specimens are placed under compressive stress. The manganese zinc specimen, however, which has a positive magnetostriction as contrasted with the negative magnetostriction of the other specimens, exhibits a decrease in remanence with compression, and would require tension to increase its remanence. The stress applied to the ferrite cores should be substantial, and increasing stress is found to improve the above-noted magnetic properties up to the verge of mechanical breakdown of the ferrite samples. One-half or even a lesser fraction of this force is, however, sufficient to produce a marked improvement in the magnetic properties involved. As a concrete illustration of the foregoing, a pressure of 300 pounds per square inch was found to nearly double the remanence of specimen #5, using the hydraulic device of Fig. 5.

Particularly good results have been obtained with ferrites of the general formula Ni_{0.3}Zn_{0.7}Fe₂O₄, which may be seen to have good magnetic properties even when unstressed. The atomic percentages, using 100 percent metal as a base, would be Fe—66.67 percent, Ni—10.00 percent, and Zn—23.33 percent in the case of a stoichiometric composition. In addition, it has been found that slight deviations of the iron content are critical, and that quite an exact stoichiometric balance must be maintained for best results. The balance between the nickel and zinc is not as critical as that between the nickel and zinc to-

gether and the iron, but still must be moderately close at a 3:7 ratio, for best results.

The characteristic curves of the stressed ferrite core specimen #1, which has the above-noted desirable chemical composition, are shown in Figs. 7 and 8. The remanence increases from 320 to 1460 gauss with compression and the maximum permeability increases from 12,600 to 36,800. The hysteresis loop of specimen 2, which has a chemical composition that deviates somewhat from exact stoichiometric balance, is shown in Fig. 9. In this case the remanence increases from 900 to 1630 gauss with applied stress, and the maximum permeability increases from 7,900 to 12,300.

The foregoing data illustrates the effect of actively applied stress in making the hysteresis loops of certain ferrites more nearly rectangular and increasing their maximum permeabilities. Ferrite cores having these properties are adapted for many high frequency applications, with the former characteristic being particularly useful in magnetic memory devices and the latter in magnetic amplifiers.

One feature of the invention which should be reiterated is that the solidifying of the constrictive plastic exerts enough force to produce the improvement in magnetic properties noted hereinbefore. While the curing plastic might have exerted such a weak force that there would be no change in the magnetic properties, or such a powerful stress that the brittle, ceramic-like ferrite cores would be cracked, we have discovered that suitable plastics will exert the proper force to greatly improve the magnetic properties of the core without deleterious mechanical fracture.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An annular polycrystalline ferrite core, and a ring of constrictive material in engagement with said core and extending outwardly therefrom with the radial dimension of the constrictive ring from the core to the periphery of said ring being substantially greater than its axial thickness.

2. An annular ferrite core having substantial negative magnetostriction, a plurality of conductive paths inductively coupled to said core, and a rigid styrene-polyester resin encasing said core and applying stress to said core having a maximum compressive component in a circumferential direction in said core.

3. An annular ferrite core, and an insulating constrictive body of plastic material having a shrinkage factor in the order of magnitude of nine percent extending outward radially from said core and formed to impose a stress on said core which has a maximum component in a circumferential direction.

4. An annular ferrite core, and a ring of insulating material extending radially outwardly from said core and exerting an inward force on said core of a magnitude greater than fifty pounds per square inch.

5. In combination, a high frequency source, a ferrite core coupled to said source, and means for imparting a stress to said core producing a substantial compressive component in the direction of the principal magnetic field in said core which is greater in magnitude than any compressive component in a direction perpendicular to said direction of principal magnetic field.

6. In combination, a high frequency source, a ferrite core coupled to said source, and means including a plastic coating on said core for imparting a stress to said core producing a substantial compressive component in the direction of the principal magnetic field in said core which is greater in magnitude than any compressive component in a direction perpendicular to said direction of principal magnetic field.

7. The method of improving the magnetic characteristics of a high frequency ferrite core which comprises preparing an insulating constrictive plastic in liquid form, submerging said core in the constrictive liquid in such a manner that the annular distribution of said liquid adjacent the outer periphery of said core substantially exceeds the radial dimension of said core and the annular distribution of said liquid adjacent the inner periphery of said core, and solidifying the liquid, thus placing the annular core under an active stress having a maximum compressive component in a circumferential direction therein.

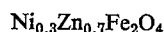
8. The method of improving the magnetic characteristics of a high frequency ferrite core which comprises preparing an insulating constrictive plastic in liquid form, submerging said core in the constrictive liquid in such a manner that the annular distribution of said liquid adjacent the outer periphery of said core substantially exceeds the radial dimension of said core and the annular distribution of said liquid adjacent the inner periphery of said core, solidifying the liquid, during the solidification of said liquid energizing an electrical circuit magnetically linked with said core in a direction to reduce the circumference of said core and deenergizing said circuit on solidification of said liquid, thus placing the annular core under an active stress having a maximum compressive component in a circumferential direction in said core.

9. In combination, a body of rigid constrictive insulating material, and a polycrystalline ferrite core embedded therein, said insulating material formed to produce a stress in said core having a maximum compressive component in the direction in which the principal magnetic field is induced in said core.

10. An annular ferrite core having an approximate chemical formula of $\text{Ni}_{0.3}\text{Zn}_{0.7}\text{Fe}_2\text{O}_4$, a plurality of conducting paths inductively coupled to said core, and means for applying a continuous stress to said core which has a maximum compressive component in a circumferential direction in said core.

11. In combination, a source of pulses of high repetition rate, and a ferrite core coupled to said source, said core having substantial negative magnetostriction, and said core embedded in a constrictive plastic formed to impose on said core a maximum compressive stress in the direction of the magnetic field in said core.

12. A stressed magnetic core having an approximate composition as given by the chemical formula



means for applying a magnetic field to said core, and means including a rigid body of insulating material permanently associated with said core for maintaining said core under stress having a major uniform component in the direction of said magnetic field.

13. An annular polycrystalline magnetic ferrite core of the chemical formula $\text{Ni}_{0.3}\text{Zn}_{0.7}\text{Fe}_2\text{O}_4$, and means including a plastic insulating coating permanently associated with said core for applying to said core a stress which has a maximum component in a circumferential direction.

14. An annular ferrite core having substantial negative magnetostriction, a coil coupled to said ferrite core, and an insulating constrictive matrix of a plastic material encasing said core and coil and formed so as to impose on said core a stress having a maximum compressive component in a circumferential direction.

15. A polycrystalline ferrite core, means for applying a magnetic field to said core, and hydraulic means for applying stress thereto having a maximum compressive component in the direction of the magnetic field in said core.

16. An annular ferrite core, and an insulating constrictive matrix of a plastic material encasing said core, with the axial thickness of said core being substantially the same as that of said matrix, but with the radial extent of that portion of said constrictive matrix adjacent the outer periphery of said core being substantially greater

than that of said core or that portion of the matrix adjacent the inner periphery of said core.

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